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Research Report

Water Scarcity Variations within a Country: A Case Study of Sri Lanka

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and
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International Water Management Institute

Research Reports

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The International Irrigation Management Institute, one of sixteen centers supported by the Consultative Group on International Agricultural Research (CGIAR), was incorporated by an Act of Parliament in Sri Lanka. The Act is currently under amendment to read as International Water Management Institute (IWMI).

Contents

Summary

Several studies on present and future water scarcities rank Sri Lanka as a country with either little or no water scarcity or moderate water-scarcity conditions. None of these studies have considered the spatial and temporal variations of water availability and demand within the country. This report examines the variations of water supply and demand and the differences of water scarcities between different districts in Sri Lanka under both present conditions and projected conditions in 2025.

The results of this study indicate wide temporal and spatial variations of available water resources and demand. The total utilizable water resources per unit area in districts range from 0.03 meter to 1.43 meters in the *maha* (wet) season and from 0.02 meter to 1.7 meters in the *yala* (dry) season. On the demand side, the dry zone accounted for more than 90 percent of the current withdrawals, whereas only 44 percent of the population lived there in 1991. The heavy withdrawal in the dry zone was mainly due to the higher share of irrigation demand.

Water demand for the year 2025 is projected under two irrigation scenarios. The first scenario assumes the same irrigation sector efficiency, i.e., the ratio of irrigation requirement to primary irrigation withdrawal in 2025 at the current level. The second scenario assumes increased irrigation efficiency in 2025. Domestic and industrial demands are projected at the level of basic human needs or at the current level of withdrawals, whichever is higher. Demand projections for 2025 show that the dry zone will again account for more than 90 percent of the total water withdrawals. With an increased irrigation efficiency scenario, the total withdrawal demand in the country (and especially in the dry zone) can be reduced by almost half.

According to most scarcity criteria, the national statistics indeed show no serious present or future water scarcity. However, a different picture emerges at the district level. Five districts (25% of the total land area) in the maha season, and nine districts (43% of the total land area) in the yala season withdrew more than 50 percent of their water resources in 1991. These districts already have absolute water-scarce conditions according to some criteria.

A few more districts will enter into the absolute water-scarce category in 2025 under scenario 1. However, if the irrigation sector efficiency can be doubled by 2025, only four districts in the maha season and nine districts in the yala season will have severe water-scarce conditions. Though these districts are identified as being severely water-scarce, they can meet their 2025 demand by withdrawing at or below the current withdrawal levels.

Whether the country has the institutional and financial capacity to attain the high irrigation efficiency needed in the second scenario is not clear. However, at the current level of irrigation efficiency, the majority of the districts in the dry zone—Ampara, Anuradhapura, Batticaloa, Hambantota, Jaffna, Killinochchi, Kurunegala, Mullaitiv, Polonnaruwa, Puttalam, Trincomalee, and Vavunia—will face severe seasonal or year-round absolute water-scarce conditions. These districts in the dry zone share more than 75 percent of the irrigation withdrawals at present and also the highest increase in withdrawals projected for the future. Therefore, the water scarcities in the dry zone will have a severe impact on the country's future food production.

Also, contrary to common belief, Galle district in the wet zone is also identified as having severe water-scarce conditions in an economic sense.

Though this district has sufficient water resources, it will have to at least double its withdrawal to meet the 2025 demand.

The present study clearly illustrates that the statistics in the form of aggregated information at national level sometimes mask issues of local water scarcity. This is especially true when vast spatial and seasonal variations of water supply and demand are present. Sri Lanka, even though a small country, is a good example with such variations. When the same indicators are used at subunit level, a substantial area of the country comes under severe water-scarce conditions. A knowledge of subunit level water scarcities is very important because most of the food requirement of the country at present comes from water-scarce regions and projected additional requirements are also to be met by the same regions.

Water Scarcity Variations within a Country: A Case Study of Sri Lanka

Upali A. Amarasinghe, Lal Mutuwatta, and R. Sakthivadivel

Introduction

Several studies on present and future water scarcities rank Sri Lanka as a country with either little or no water-scarcity or moderate water-scarcity conditions (Falkenmark, Lundqvist, and Widstrand 1989; Engleman and Leroy 1993; Raskin et al. 1997; Seckler et al. 1998; Seckler, Barker, and Amarasinghe 1999). These studies used the aggregated information presented in the form of statistics at national level. However, the aggregated statistics on water scarcity at national level are sometimes misleading for countries with large regional variations. All these earlier studies had ignored spatial and temporal variations of water availability and demand from their water-scarcity calculations. The main objective of this study is to assess the spatial and seasonal variations of water supply and demand, and also scarcities at district level in Sri Lanka.

Sri Lanka experiences high seasonal and spatial variations in rainfall due to the bimonsoonal climatic pattern (northeast monsoon from October to March and southwest monsoon from April to September). It has two seasons: maha season from October to March and yala season from April to September. Rainfall patterns divide the country primarily into two climatic zones: the wet zone and the dry zone. The wet zone, comprising one fourth of the land area receives an average of 2,350 mm of annual rainfall distributed in the two seasons. The rest of the area, called the dry zone, receives an average of 1,450 mm of annual rainfall. In the dry zone, more than two-thirds of the annual rainfall is received during the maha season, and more than 70 percent of the maha season rainfall is received from October to December.

On the demand side, the agriculture sector used 96 percent of the total withdrawals in 1991 (ESCAP 1995). This was mainly for rice irrigation. More than 85 percent of the 1991 irrigated rice area was in the dry zone, which has the most demand for water; on the other hand, the water availability in the wet zone is higher. If water is scarce in regions where most of the withdrawals are for irrigation, the impact on future food production will be very significant for the following reasons.

First, Sri Lanka withdrew a mere 31 liters/person/day in 1991 for the domestic and industrial sectors (ESCAP 1995). This level of supply is even below the minimum level for the basic water requirements for domestic purposes (Gleick 1996). The changing socioeconomic conditions will demand more water for domestic purposes. Along with this, the rapid growth in the industrial sector will also demand more water.

Second, the greater part of the rice-irrigated area is in the dry zone. Recent trends show that the rice area under rain-fed conditions has not recorded any increase (Aluwihare and Kikuchi 1991). In fact, a decreasing trend in rain-fed area cultivation has been seen after the late 1970s. Also, no significant increase in yield has been seen in either rain-fed or irrigated rice during recent years. All indications are that the yield per unit of land has reached a plateau since the 1980s (Wijayaratna and Hemakeerthi 1992). Therefore, if the current rates of growth in rice area and in rice yield are indications for future development, production increases in rice may have to come totally from increasing the gross irrigated area. However, the greater part of the irrigated rice area is in the dry zone, and the water availability there is less than that in other areas. Additionally, competition from domestic and industrial sectors will also increase. Therefore, water scarcities in the dry zone will have a severe impact on meeting the additional food requirements of the increasing population.

In this respect, it is of vital importance to understand the regional scarcities of water and their impact on future food production. Therefore, the main objectives of this report are to assess:

- the differences in the present and future situations of water supply and demand at district level

- the existence of water scarcity at present and their differences at district level

- the district-level differences of future water scarcities assuming that the additional rice production required in the future would have to be met totally from irrigated agriculture

In most studies in Sri Lanka, river discharges to the sea (runoff) are assessed under average rainfall conditions. Such an assessment is substantially influenced by the extreme rainfall years. In fact, this is the case in Sri Lanka where seasonal rainfall distribution is skewed to the right due to years with extremely high rainfall. The use of appropriate percentiles of the rainfall distribution will overcome the undue influence of years of extreme rainfall in averaging. What percentile of the rainfall distribution is appropriate is the next question. If one uses the median or the 50th percentile (50 percent exceedence probability rainfall), then in the long run the actual value will exceed the assessed value every other year. On the other hand, the use of the 25th percentile (75 percent exceedence probability rainfall) will imply that actual runoff in the long run will exceed the estimated runoff in 3 out of every 4 years. Moreover, 75 percent exceedence probability rainfall is used for river basin planning studies. Therefore, we have selected the 75 percent exceedence probability rainfall for assessing utilizable river runoff.

Future water demands at district level are studied under two scenarios: The first scenario is that the irrigation sector efficiency will be the same in the future as at present. The second scenario assumes higher irrigation efficiency than at present. These scenarios will be discussed in more detail in the respective sections.

Of course, there are certain limitations to our analysis. Our estimates of current water availability and demand for a unit may slightly differ from the actual value of the unit. This is mainly due to the difficulty in obtaining reliable data on water supply and demand at district level. However, we believe that our method of estimation would enable us to compare the present and future water supply and demand between districts in a consistent manner. This would also give enough information to illustrate the magnitude of water scarcity at district level.

For our analysis, we consider 1991 as the base year to assess the current status, and the year 2025 for future projections. In the next section, three water scarcity criteria described in the literature are briefly introduced. In section 3, the present and future water supply and demand situations are discussed. The differences of water scarcity indicators at district level and the distribution of population, land area, and irrigated area for different scarcity categories are discussed in section 4. The concluding remarks are in section 5.

Water Scarcity Indicators

Falkenmark, Lundqvist, and Widstrand (1989) have used annual per capita water availability to define water scarcity thresholds. In their criterion of water scarcity, a country is considered water-scarce if the per capita annual water supply falls below 1,700 cubic meters (m^3). Above this level of per capita water supply, water scarcities are considered to be rare and, if they exist, they are only problems within a few localities. Below the 1,700 m^3 level, a country faces seasonal or regular water-stressed conditions. If the annual per capita water supply falls below 1,000 m^3, water shortages begin to hamper the health and well-being of human beings, and if it falls below 500 m^3, shortages are severe constraints to human life. Hereafter we refer to this as the Falkenmark indicator. We call the four categories as severe, medium to severe, moderate, and little or no water scarcity (table 1).

In a recent UN study (Raskin et al. 1997), water scarcity thresholds were defined in terms of the percent of water resources withdrawn for different uses. A country is considered to be severely water-scarce if the withdrawals exceed 40 percent of the total supply. Above this level, countries will have to depend more and more on desalination or on the use of groundwater in an unsustainable manner. In this category, the water scarcity is the limiting factor to economic growth. Countries with withdrawals from 20 to 40 percent are considered to have medium to severe water scarcity. Countries in this range are required to take effective steps to manage their water supply and demand in a way that the withdrawals for different sectors are sustainable. Countries with withdrawals from 10 to 20 percent are considered to have moderate water scarcity, while those with less than 10 percent withdrawals are considered to have little or no water scarcity. Hereafter this will be referred to as the UN indicator.

In a study by the International Water Management Institute (IWMI) (Seckler et al. 1998; Seckler, Barker, and Amarasinghe 1999), water scarcities are defined in terms of two factors: The first is the future withdrawal as a percent of the available water resources. The second is the increase in additional water withdrawal needs. A country is defined to be absolutely water-scarce if the demand is more than 50 percent of the available water resources. Scarcities of other countries are ranked according to their future development needs. For example, a country is severely water-scarce in an economic sense, if the future demand is more than double the present withdrawal level. In this report, absolute water scarcity is called severe water-scarce category, while the severe economic water-scarce category is called medium to severe-water scarce category (table 1).

TABLE 1.
The water scarcity levels of the three indicators.

	Indicator and criteria		
	Falkenmark	UN	IWMI
Scarcity level	I_F = Annual per capita water supply	I_{UN} = Withdrawal as a % of water supply	I_{IWMI1} = Withdrawal as a % of water supply I_{IWMI2} = Future withdrawals as a % of current withdrawals
Severe	$I_F < 500m^3$	$I_{UN} > 40\%$	$I_{IWMI1} > 50\%$
Medium to severe	$500m^3 < I_F < 1,000m^3$	$20\% < I_{UN} < 40\%$	$I_{IWMI1} < 50\%$ & $I_{IWMI2} > 200\%$
Moderate	$1,000m^3 < I_F < 1,700m^3$	$10\% < I_{UN} < 20\%$	$I_{IWMI1} < 50\%$ & $125\% < I_{IWMI2} < 200\%$
Little or no	$1,700m^3 < I_F$	$I_{UN} < 10\%$	$I_{IWMI1} < 50\%$ & $I_{IWMI2} < 125\%$

Water Supply and Demand

Domain of Analysis

An ideal domain for conducting water resources analysis is a hydrological unit such as a river basin. However, in this report the administrative district is considered as the basic unit of analysis. For several reasons, most important of which is that population data, some water supply data, and water-use-related data (which are very important to our study) are available at administrative unit level. Also, from an analysis at district level, a regional picture at larger administrative units such as the provincial or at climatic zone levels can be obtained by summation.

In Sri Lanka, several administrative units share the water of major river basins. For example, the Mahaweli basin (figure 1) covers about 18 percent of the land area, and contributes to the water resources of several administrative districts in both the wet zone and the dry zone. Likewise, the Kalu ganga and Kelani ganga basins, which cover more than 8 percent of the land area, lie completely inside the wet zone benefiting from the rainfall from several administrative districts. At present, there are no apparent major conflicts among administrative districts in sharing the water resources of river basins. However, a changing socioeconomic and political environment will increase the competition among districts for water resources of these basins. Therefore, it is important to have information on the current supply and demand situation of water and also of the water scarcities (if they exist) at district level and also at larger administrative unit levels such as the provincial level.

There are 25 administrative districts in Sri Lanka and in 1991 its total population was 17 million (table 2). The wet zone contains 9 districts, mainly in the western, central, and southern provinces. These districts, with only 25 percent of the land area, contain 56 percent of the total population. The remaining districts are considered to be in the dry zone.

Water Resources

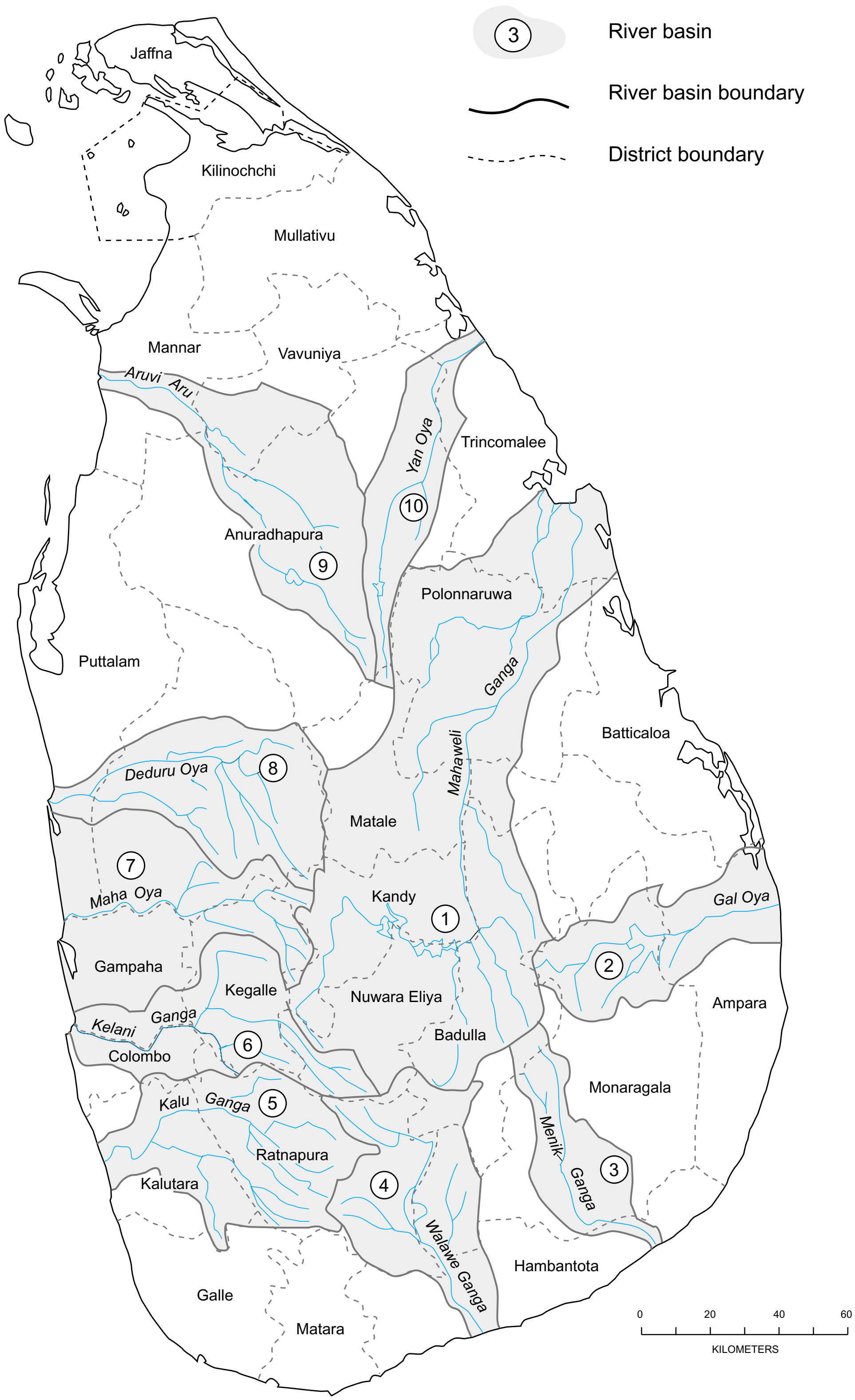
The water resources for a district consist of the following components (Seckler et al. 1998):

- surface inflow to a district generated from the precipitation within the district and inflow from neighboring districts
- surface outflow, i.e., that portion of surface inflow getting out of the district
- change in storage (net change in reservoir storage is accounted for, while net change in groundwater storage is assumed to be negligible)

Then the utilized flow is the sum of the surface inflow and the change in storage minus the surface outflow. Most of the above components at district level are not measured, and need to be estimated. For example, the inflows and the outflows from one district to another are not recorded. Therefore, a different methodology has to be adopted for computing the net inflows and surface runoff. The suggested methodology is based on the computation of utilizable seasonal runoff of a basin and apportioning it among districts contributing to that discharge, proportional to the area of contribution. As discussed in the introductory section, the potentially utilizable flow in this study is based on the 75 percent exceedence probability rainfall, and not on the average rainfall. The following are the steps involved in the computation:

- Identify basins having a fairly long period of record of discharge and rainfall, and select a period where the discharges are not affected unduly by storage structures within the basin.
- For the period selected, convert values of monthly rainfall and discharges into values of seasonal rainfall and discharges.

FIGURE 1.
Major river basins in Sri Lanka.



- Develop seasonal rainfall-runoff relationships.

- Using 75 percent exceedence probability seasonal rainfall, determine basin seasonal runoff from the rainfall-runoff relationships.

- For basins where seasonal rainfall-runoff relationships cannot be established, the runoff is computed by linearly interpolating the runoff per unit area of adjoining basins where rainfall-runoff relationships exist.

- Superimpose the district boundary map on the river basin map and identify districts and their areas that constitute each basin.

- Seasonal runoff of a basin is apportioned to each district proportionally to the 75 percent exceedence probability total rainfall received on the area of each district that intersects the basin.

TABLE 2.
Land area, population, per capita domestic and industrial withdrawals, and storage capacity.

Unit	Land area	Average rainfall	1991 Population Total	Urban as a % of total	With piped water supply	1991 Per capita per day domestic withdrawal	1991 Industrial Output	Withdrawal per capita per day	Potential storage capacity
	1,000km²	mm	million	%	million	liters	billionRS	liters	km³
	C1[1]	C2	C3[1]	C4	C5[1]	C6	C7[1]	C8	C9[1]
Sri Lanka	65.6	1,672	17.3	21	4.6	31	112	31	6.05
Wet Zone (WZ)	23.3%	2,353	56.0%	28	64%	35	89%	49	26%
Dry Zone (DZ)	76.7%	1,465	44.0%	13	36%	26	11%	8	74%
Districts-WZ									
Colombo	1.1%	2,528	11.4%	74	24%	65	48%	132	0%
Galle	2.5%	2,344	5.5%	21	5%	31	2%	9	0%
Gampaha	2.4%	2,210	8.9%	28	10%	35	30%	105	0%
Kalutara	2.1%	2,655	5.5%	21	6%	31	1%	4	0%
Kandy	3.0%	2,155	7.3%	13	6%	26	1%	4	21%
Kegalle	2.6%	2,388	4.4%	8	3%	22	1%	10	0%
Matara	2.0%	2,217	4.5%	11	4%	25	1%	7	0%
Nuwara Eliya	2.7%	2,122	3.1%	7	2%	22	3%	33	0%
Ratnapura	5.0%	2,535	5.5%	7	4%	22	2%	9	5%
Districts-DZ									
Ampara	6.7%	1,509	2.8%	14	2%	26	1%	6	26%
Anuradhapura	10.9%	1,305	4.1%	7	3%	22	0%	0	13%
Badulla	4.4%	1,776	4.2%	8	3%	23	1%	7	1%
Batticaloa	4.4%	1,574	2.4%	24	3%	33	1%	7	3%
Hambantota	4.0%	1,691	3.0%	10	2%	24	0%	1	2%
Jaffna(1)	1.6%	1,104	5.0%	33	6%	38	1%	3	0%
Killinochchi	1.9%	1,102	0.6%	9	0%	23	1%	27	3%
Kurunegala	7.3%	1,654	8.3%	4	5%	20	1%	3	4%
Mannar	3.0%	1,072	0.8%	14	1%	26	1%	21	2%
Matale	3.0%	1,690	2.4%	11	2%	24	0%	5	1%
Monaragala	8.6%	1,587	2.0%	2	1%	19	3%	40	1%
Mullaitivu	4.0%	1,145	0.5%	9	0%	23	1%	30	0%
Polonnaruwa	5.0%	1,532	1.8%	8	1%	22	0%	0	8%
Puttalam	4.7%	1,478	3.5%	13	3%	25	2%	17	2%
Trincomalee	4.2%	1,426	1.8%	32	2%	38	1%	9	4%
Vavuniya	3.0%	1,172	0.7%	19	1%	30	1%	24	3%

[1]Wet-zone, dry-zone, and district values are given as a percent of the Sri Lankan total.

- Net diversions from outside the district and potential carryover from one season to another were added to the computed runoff to estimate the total water supply available to the district.

Contribution to Surface Runoff

Based on the above methodology, the seasonal runoff of basins at 75 percent exceedence probability rainfall is calculated first (see appendix A for more details). The contributions of districts to the total runoff are worked out next (table 3). The runoff figures indicate wide spatial and seasonal variations. For example, though the total maha season runoff in the two climatic zones is similar, the yala season total runoff is significantly different. The maha season runoff per unit area in the dry zone is less than one-third of that in the wet zone (C2, table 3). The yala season runoff per

TABLE 3.
Seasonal water resources.

	Maha season						Yala season					
	Contribution to runoff		Carry-over	Net divers-	Water resources		Contribution to runoff		Carry-over	Net diver-	Water resources	
Unit	Total	Depth	storage	ions	Total	Depth on land area	Total	Depth	storage	sions	Total	Depth on land area
	km³ C1[1]	m C2	km³ C4[1]	km³ C5	km³ C6[1]	m C7	km³ C8[1]	m C9	km³ C11[1]	km³ C12	km³ C13[1]	m C14
Sri Lanka	24.29	0.37	0.96	0.00	22.99	0.35	16.95	0.26	2.26	0.00	18.25	0.28
Wet zone (WZ)	51%	0.81	100%	-1.15	49%	0.74	81%	0.90	43%	-0.74	71%	0.85
Dry zone (DZ)	49%	0.24	0%	1.15	51%	0.23	19%	0.06	57%	0.74	29%	0.10
Districts-WZ												
Colombo	2%	0.77	3%		2%	0.77	4%	0.88	1%		3%	0.88
Galle	7%	0.99	0%		7%	0.99	11%	1.13	0%		10%	1.13
Gampaha	3%	0.53	0%		4%	0.53	5%	0.56	0%		5%	0.56
Kalutara	8%	1.43	0%		9%	1.43	14%	1.70	0%		13%	1.70
Kandy	4%	0.56	65%	-0.57	2%	0.27	5%	0.40	28%	-0.28	3%	0.25
Kegalle	7%	0.96	0%		7%	0.96	13%	1.27	0%		12%	1.27
Matara	4%	0.73	1%		4%	0.73	5%	0.67	0%		5%	0.67
Nuwara Eliya	5%	0.64	0%	-0.58	2%	0.30	7%	0.71	0%	-0.45	4%	0.45
Ratnapura	11%	0.82	31%		12%	0.82	18%	0.92	13%		17%	0.92
Districts-DZ		0.00										
Ampara	7%	0.39	0%		5%	0.28	1%	0.03	21%		3%	0.13
Anuradhapura	3%	0.10	0%	0.27	3%	0.11	1%	0.02	10%	0.23	3%	0.09
Badulla	6%	0.49	0%		6%	0.48	3%	0.19	1%		3%	0.20
Batticaloa	4%	0.31	0%		4%	0.30	0%	0.02	2%		1%	0.04
Hambantota	3%	0.25	0%		3%	0.23	2%	0.15	2%		2%	0.17
Jaffna(1)	1%	0.15	0%		1%	0.15	0%	0.04	0%		0%	0.04
Killinochchi	0%	0.07	0%		0%	0.06	0%	0.01	1%		0%	0.03
Kurunegala	4%	0.20	0%		4%	0.19	3%	0.11	3%		3%	0.12
Mannar	0%	0.05	0%		0%	0.03	0%	0.01	1%		0%	0.03
Matale	3%	0.39	0%	0.03	3%	0.39	2%	0.17	1%	0.03	2%	0.19
Monaragala	7%	0.29	0%		7%	0.28	2%	0.06	0%		2%	0.06
Mullaitivu	1%	0.09	0%		1%	0.09	0%	0.02	0%		0%	0.02
Polonnaruwa	6%	0.41	0%	0.79	9%	0.61	2%	0.11	7%	0.45	5%	0.29
Puttalam	1%	0.07	0%		1%	0.06	1%	0.03	2%		1%	0.05
Trincomalee	3%	0.28	0%	0.06	3%	0.27	1%	0.05	3%	0.02	1%	0.08
Vavuniya	1%	0.10	0%		1%	0.08	0%	0.02	2%		1%	0.05

[1]Wet-zone, dry-zone, and district values are given as a percent of Sri Lankan total.

unit area in the dry zone is only about 6 percent of that in the wet zone (C9, table 3). It is important to note that there also exist some substantial seasonal differences. For example, in the dry zone, the yala season runoff is about a quarter of the maha season runoff (C8, table 3).

Reservoir Storage

At present, Sri Lanka has an estimated 6 km^3 of potential storage capacity.[1] This consists of 5.25 km^3 from major reservoirs, 0.38 km^3 from medium reservoirs, and 0.41 km^3 from minor tanks.[2]

The contributions from reservoir storage to seasonal water resources are computed as described below. The storage for withdrawal for a given season is available in two ways. One is the storage available at the beginning of the season. The other is the inflow to the reservoirs during the season due to precipitation in the previous season. In the wet zone, except in the Kandy district, we assume that runoff equivalent to 100 percent of the storage capacity is available from one season to another. In the Kandy district we assume the availability as only 50 percent of the storage capacity. In the dry zone, we assume that the maha season runoff equivalent to 30 percent of the storage capacity is available for the yala season water resources, while no yala season runoff is available as storage for the maha season water resources (table 4). Certainly, the assumptions on availability of runoff as reservoir storage from one season to another can easily be lower or higher due to high variations in seasonal and annual rainfall. For example, a weak northeast monsoon and hence a lower rainfall in the maha season would reduce the maha season runoff and hence the reservoir storage available for the yala season. Net carryover runoffs as a percent of storage capacity from one season to another are found in C4 and C11 of table 3.

TABLE 4.
Carryover runoff between seasons as a percent of storage capacity.

Climatic	Carryover runoff as a % of storage capacity	
zone	Maha to yala season	Yala to maha season
Wet zone	100	100
Dry zone	30	0

Net Diversions

Under the Mahaweli Development Program, there are substantial amounts of water diverted from the wet zone area of the Mahaweli basin to the dry zone basins. The study by Sakthivadivel et al. (1995) tabulated the Mahaweli diversions to the reservoirs in the Matale, Anuradhapura, Polonnaruwa, and Trincomalee districts in the dry zone. The probable diversions at 75 percent probability level are given in C5 and C12 in table 3.

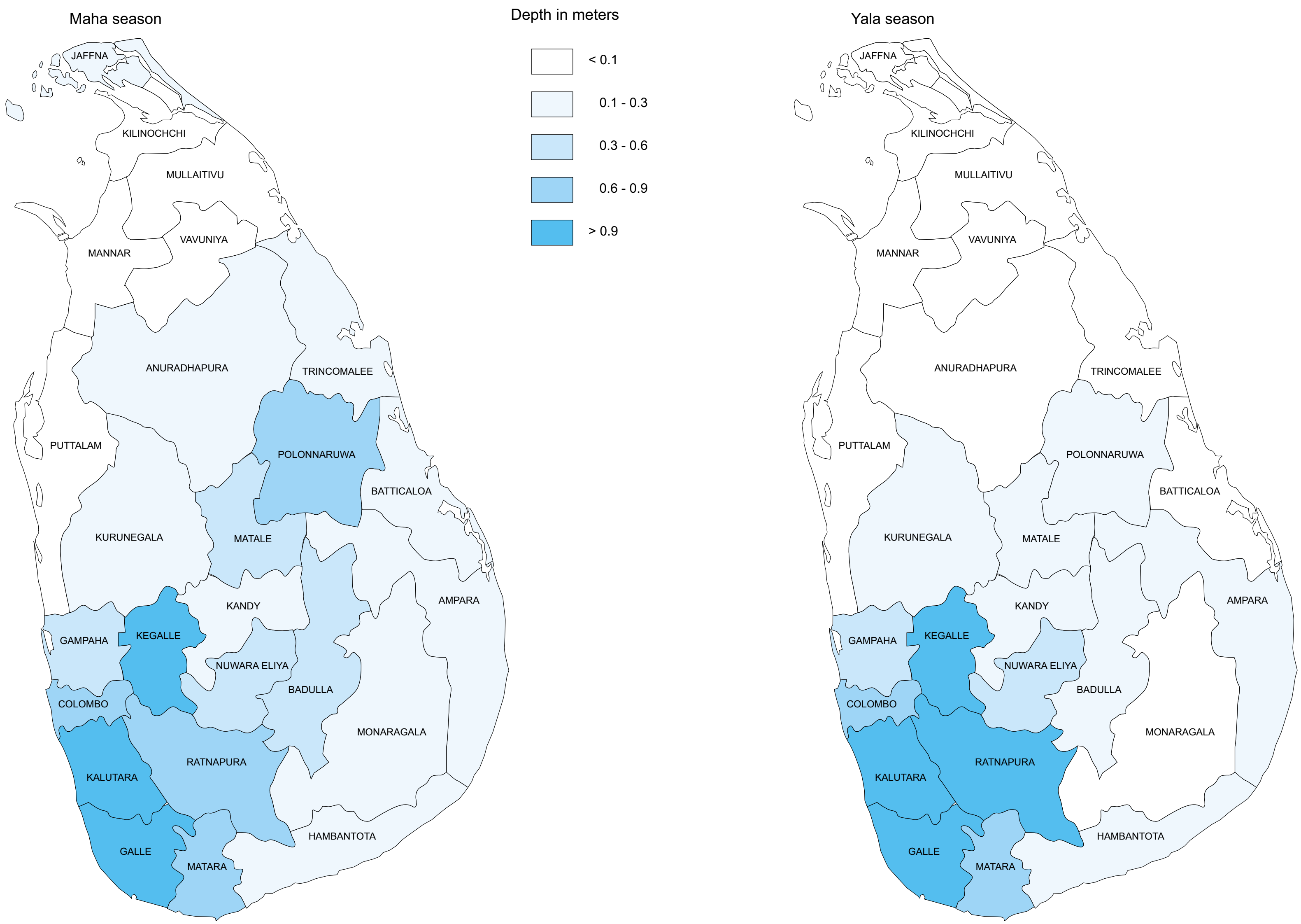
Potentially Utilizable Seasonal Water Resources

The potentially utilizable seasonal water resource for a district is the aggregate of the contribution to runoff from a district, carryover runoff as storage from the previous season, and the net diversions to the district. The total water resources of the two seasons show vast differences between districts (figure 2). Maha season water resources per unit area range from 1.43 meters in the Kalutara district in the wet zone to 0.03 meter in the Mannar district in the dry zone. Yala season water resources per unit area (C14) range from 1.7 meters in the Kalutara district to 0.02 meter in the Mullaitivu district. Though the maha season total water resources are similar in the two climatic zones (C6, table 3), the yala season totals are significantly different (C13, table 3). Of

[1]The potential storage capacity was estimated from the figures supplied in various publications by Arumugam (1969); Irrigation Department (1975); and Mahaweli Authority of Sri Lanka (1995).

[2]Storage capacity of the minor tank category may be higher than the value reported here, as data for all the minor tanks were not available (Irrigation Department 1975).

FIGURE 2.
Seasonal water resources per unit area.



the total water resources in the yala season only 29 percent is available for the dry zone.

Water Withdrawals

Based on population growth, increase in domestic demand, and on growth in industry and irrigation, ESCAP (1995) estimated that Sri Lanka's total water withdrawal in 1991 was 9.77 km^3, of which 96 percent was used by the agriculture sector and 2 percent each by the domestic and industrial sectors.

Domestic and Industrial Withdrawals in 1991

The estimated total domestic withdrawal in 1991 was the same as for the total industrial withdrawal, which was 0.19 km^3. The withdrawals to domestic sector at district level were not available for this study. However, it is known that 70 percent of the urban and 15 percent of the rural population are served by piped water (ESCAP 1995). According to the last census (Department of Census and Statistics 1995), only 21 percent of Sri Lanka's population lived in urban areas. Therefore, in the absence of withdrawal data at district level, we assumed that the domestic water withdrawal[3] for each district is proportional to the urban and rural population supplied with piped water.

Sri Lanka withdrew only 31 liters/person/day for domestic withdrawal in 1991 (C6, table 2). However, the estimates of variations between districts are substantial. These range from a maximum of 65 to a minimum of 19 liters/person/day in the Colombo and Monaragala districts, respectively.

The per capita industrial withdrawal in 1991 was 31 liters/person/day (C8, table 2). As in the domestic sector, the distributions of withdrawals at district level are not available for this study. Therefore, the industrial withdrawal[4] for a district in 1991 is assumed to be proportional to its 1991 industrial output (C7, table 2). There are substantial spatial differences of per capita industrial withdrawal. For example, the per capita industrial withdrawal in the wet zone is more than six times that in the dry zone.

Irrigation Withdrawals

Irrigated agriculture accounted for 96 percent of the 1991 water withdrawals, or 9.38 km^3. The total irrigated area in 1991 was 642,000 hectares. Of these, an area of 575,000 hectares (348,000 hectares in the maha season, 227,000 hectares in the yala season) was under rice. About 10 percent of the irrigated area was under other field crops (OFCs). There are wide variations of irrigated area between regions. For example, the districts in the dry zone contain more than 85 percent of the total annual irrigated area.

Seasonal irrigation withdrawal (IRR)[5] for a given district is assumed to be proportional to the seasonal irrigation requirements for the area irrigated by the districts. The irrigation requirement of the two seasons is the sum of net evapotranspiration (NET) of the first 5 months in the maha season and first 4 months in the yala season. The net evapotranspiration for a month is taken as the potential evapotranspiration (ETo) minus the effective rainfall. The effective rainfall for a district is calculated as follows: First, the difference between the average rainfall volume and

[3]The domestic withdrawal for i^{th} district, *DOM(i),* is estimated as, $DOM(i) = \frac{[p(i) \times .70 + (1 - p(i)) \times .15] \times P(i)}{\sum_j [p(j) \times .70 + (1 - p(j)) \times .15] \times P(j)} DOM$, where *p(i)* is the percent of urban population and *p(J)* is the percent of the total population of the i^{th} district, and *DOM* is the total domestic withdrawal.

[4]The industrial withdrawal for the i^{th} district, *IND(i)* is estimated as *IND (i) = ind(i) x IND,* where *ind(i)* is the percent contribution from the i^{th} district to the total industrial output, and *IND* is the total industrial withdrawal.

[5]The irrigation withdrawal *IRR(i,j)* for the i^{th} district in the j^{th} season is estimated as $IRR(i,j) = \frac{NET(i,j)}{\sum_i \sum_j NET(i,j)} IRR$, where *NET(i,j)* is the total irrigation requirement for the i^{th} district in the j^{th} season, and *IRR* is the total annual agriculture withdrawal.

the runoff volume generated from that rainfall is calculated. Then 90 percent of this difference is taken as the effective rainfall while the other 10 percent is lost as non-recoverable percolation. The calculation of NET for each district will be discussed in more detail in appendix B.

Irrigation Efficiency and Water Recycling

Recycling of water within basins in Sri Lanka, as in many locations worldwide, plays an important role in the understanding of water supply and demand. When water is withdrawn for irrigation, part of the water is consumed by evapotranspiration. Part of the water then flows out of the irrigation system either along the surface or through the groundwater system. If another irrigation system uses the outflow again, we consider this as recycled water.

In a basin or district, we define primary water as water withdrawals originating from runoff, or as augmented flows to the area, but excluding recycled water. If there were no recycling of water, the sum of all withdrawals would be equal to primary water. With recycling, the sum of all withdrawals is greater than the primary water. An important point is that water consumption from withdrawals cannot exceed primary water.

Within an irrigation project, we define *project efficiency* as the ratio of NET to irrigation withdrawal, i.e.,

Project efficiency = NET/Total withdrawals

The project efficiency within a district or basin is the ratio of NET to the sum of all withdrawals. We define *irrigation sector efficiency* as the ratio of NET within a district or basin to primary water, i.e.,

Sector efficiency = NET/Primary water

If there is recycling, the irrigation sector efficiency is higher than project efficiency. Irrigation sector efficiency tells us more about the degree of scarcity than project efficiency but is much harder to estimate. Values are often available for efficiencies of various projects, but it is rare to find values of sector efficiency. Therefore, we need a way to convert average project efficiency to sector efficiency.

Let us define the *multiplier (M)* as the ratio of total withdrawals to primary water. That is:

Total withdrawals = Primary water x M

Using the relationships in 1 and 2, we find that:

Sector efficiency = M x Project efficiency
(MxProject efficiency cannot be greater than 1)

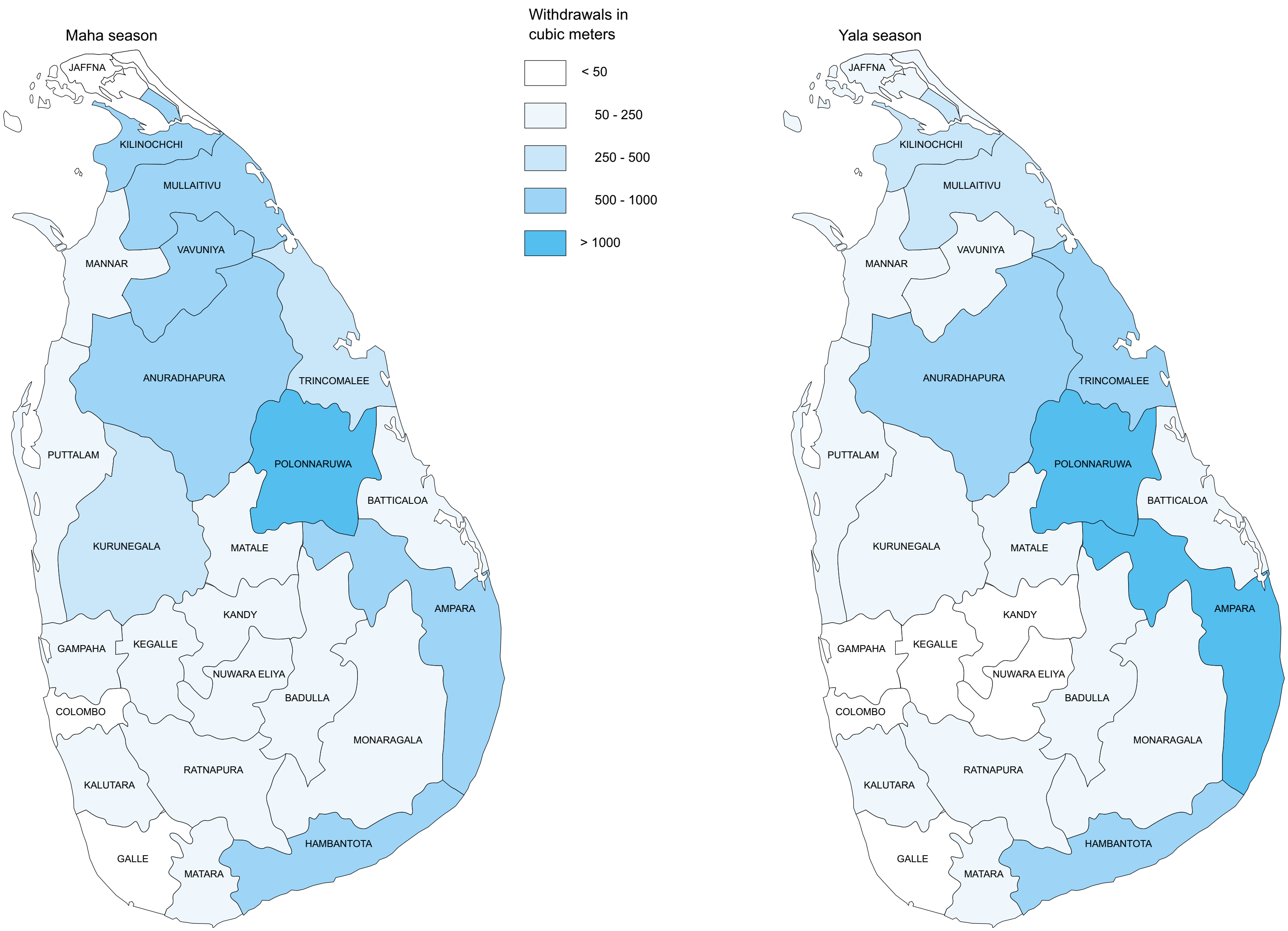
This tells us that in order to increase sector efficiency, we must either improve the project efficiency or increase the multiplier.

Unfortunately, there is insufficient information on recycling and sector efficiency. On the other hand, we know that information on withdrawals includes recycling, and thus estimates of efficiencies and water supplies are misleading. So, based on our experience, we assume a multiplier of 4/3, which implies that one-third of the primary water is recycled.

Primary Irrigation Withdrawals

There are significant differences of primary irrigation withdrawals between districts. The dry zone district's share of the total is 82 percent in the maha season and 92 percent in the yala season. This is mainly due to the high share of irrigation withdrawals. In terms of per capita withdrawals, figure 3 shows the extent of the differences between districts. While some districts in the wet zone have less than 50 m^3 per capita water withdrawals, districts in the dry zone have more than 500m^3, and some exceed even 1,000 m^3 per capita water withdrawals.

FIGURE 3.
Per capita water withdrawals in 1991.



Demand Projections

Irrigation

We assume that one-third of the primary irrigation withdrawals will be recycled in 2025, i.e., a multiplier of 4/3. Irrigation demand in 2025 is assessed under two scenarios. The first scenario assumes the same irrigation sector efficiency in 2025 as at present. In the second scenario, irrigation sector efficiency in 2025 is expected to double the current levels.

Rice is the major irrigated crop in Sri Lanka (about 90% in each season). We project the growth of rice irrigated area first. For both scenarios, growth in rice irrigation for 2025 was computed using the following assumptions:

- The level of per capita rice production (aggregate of irrigation and rain-fed) will stay the same through the period 1991–2025. This amounts to assuming the same self-sufficiency ratio in 2025 as at present.

- The yield in both irrigated and in rain-fed rice in 2025 will be 10 percent greater than in 1991 due to improved exogenous factors such as improved fertilizer, better technology, etc.

- The additional rice production in 2025 will come totally from the irrigation sector.

Under the above assumptions, first we calculate the required growth in rice irrigated area (table 5). The gross irrigated rice area in 1991 was 69 percent of the total rice cultivated area (row 2, table 5). The estimated yield was 3.84 tons/hectare under irrigation, and 2.60 tons/hectare under rain-fed cultivation (Samad 1997). This shows that 77 percent of the total rice production in 1991 was from irrigation (row 5, table 5).

According to the United Nations medium projections (UN 1995), the Sri Lankan population will increase by 45 percent during the period 1991–2025. Therefore, under the first assumption, the total rice demand in 2025 will be 4.187 million metric tons (row 7, table 5). The second assumption of 10 percent growth in yield would give 3.176 million metric tons of productions from the existing irrigated and rain-fed land (row 10, table 5). This amounts to 1,011 metric tons of additional rice production in 2025 (row 11, table 5).

TABLE 5.
Growth in rice irrigated area from 1991 to 2025.

Year	Row	Factor	Unit	Irrigation	Rain-fed	Total
1991	1	Gross area	1,000 ha	575	261	836
	2	% of total	%	69	31	-
	3	Yield	mt/ha	3.84	2.60	-
	4	Total production	1,000 mt	2,210	677	2,887
	5	% of total	%	77	23	100
2025	6	Population growth	%	-	-	145
	7	Rice demand	1,000 mt	-	-	4,187
	8	Growth in yield	%	10	10	-
	9	Yield	mt/ha	4.22	2.86	-
	10	Production from 1991 area	1,000 mt	2,431	745	3,176
	11	Total additional production requirement	1,000 mt	1,011	-	1,011
	12	% additional production	%	100	0	-
	13	Additional production	1,000 mt	1,011	0	1,011
	14	Additional required area	1,000 ha	239	0	241
	15	Gross area	1,000 ha	814	261	1,077
	16	Increase in area	%	42	0	29

Under the last assumption, additional rice production will have to be obtained only by increasing the irrigated area. To obtain the additional demand, the irrigated area has to be increased by 42 percent (row 16, table 5).

The change in area—42 percent—from 1990 to 2025 is computed only for rice irrigation. Since the production and yield data for OFCs are not available, we assume that the OFC irrigated area will also increase by 42 percent in 2025. In calculating the future demand, we ignored the fact that that there is no potential for an increase in irrigated area in some districts, especially those in the wet zone. Also we ignored the possible losses of rain-fed area due to expansion in irrigated area. If these are considered, the required growth in irrigated area in some districts may be higher than the value estimated here.

Irrigation demand under the first scenario is estimated at 16 percent project efficiency level, or 22 percent irrigated sector efficiency level. Under the second scenario, sector efficiency is assumed to be 44 percent.

Domestic and Industrial

The demand projections for the domestic and industrial sectors are based on meeting at least the basic human requirement or keeping the present level of per capita water withdrawals or both. Gleick (1996) defined basic water requirement (BWR) for human needs in terms of: drinking water for survival, water for human hygiene, water for sanitation services, and water for modest household needs for preparing food. He suggested a minimum level of 50 liters/person/day for domestic use. The present per capita domestic withdrawals of most districts are below this level. We project the 2025 domestic needs at either the BWR of 50 liters/person/day, as suggested by Gleick, or the present withdrawal level, if the latter is higher.

We also assume at least 50 liters/person/day for 2025 per capita industrial demand. In the majority of the districts per capita industrial supply in 1991 was well below this level. Only two districts (Colombo and Gampaha) had withdrawn more than 50 liters/person/day. The 2025 demand of these districts is projected at the 1991 per capita level.

Total Demand

The total demand projections for the wet and dry zones are given in table 6. Because of its substantial share in irrigation, the dry zone districts will require more than 80 percent of the total demand under both scenarios. At the same time, because of high contribution to irrigation demand, the total water demand in Sri Lanka, especially in the dry zone, can be reduced by almost one-half under the increased irrigation efficiency scenario.

TABLE 6.
2025 Demand projections.

	Maha season						Yala season					
	D&I[1]	Irrigation		Total			D&I	Irrigation		Total		
Unit		S1[2]	S2[3]	S1	S2	S2/S1		S1	S2	S1	S2	S2/S1
	km³	km³	km³	km³	km³	%	km³	km³	km³	km³	km³	%
	C1[4]	C2[4]	C3[4]	C4[4]	C5[4]	C6	C7[4]	C8[4]	C9[4]	C10[4]	C11[4]	C12
Sri Lanka	0.53	4.81	2.41	5.34	2.93	55%	0.53	5.18	2.59	5.71	3.12	55%
Wet zone	62%	18%	18%	23%	26%	64%	62%	9%	9%	14%	18%	71%
Dry zone	38%	82%	82%	77%	74%	52%	38%	91%	91%	86%	82%	52%

[1]D&I = Domestic and industrial.
[2]Scenario 1.
[3]Scenario 2.
[4]Wet-zone and dry-zone values are given as a percent of Sri Lankan total.

Water Scarcity Indicators: District-Wise Distribution

Water scarcity of a district can be due to low water supply or high demand or both. The per capita water resources, demand with respect to supply, and the increase in demand are given in table 7. Table 8 shows the scarcity level of Sri Lanka, two climatic zones, and the districts according to the three criteria: Falkenmark, UN, and IWMI. The letters “S,” “MS,” “M,” and “N,” respectively, in table 8 indicate that a unit has either severe, medium to severe, moderate, or little or no water scarcity. The “MS” and “M” in the IWMI criteria indicate severe and moderate economic water scarcity, respectively. The lower case letters: “b,” “m,” and “y” indicate whether the indicated level of water scarcity is in both seasons, only in the maha season, or only in the yala season, respectively. For example “S-m” indicates that the unit is severely water scarce in the maha season but not in the yala season.

TABLE 7.
Per capita water resources and water withdrawals as a percent of water resources.

Unit	Per capita annual water resources		Maha season					Yala season				
			Withdrawal as % of water resources			2025 withdrawal - % change from 1991 withdrawal		Withdrawal as % of water resources			2025 withdrawal - % change from 1991 withdrawal	
	1991	2025	1991	2025				1991	2025			
				S1	S2	S1	S2		S1	S2	S1	S2
	m^3	m^3	%	%	%	%	%	%	%	%	%	%
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Sri Lanka	2390	1645	16	23	13	49	-18	21	31	17	49	-19
Wet zone (WZ)	2513	1730	7	11	7	57	0	4	6	4	67	19
Dry zone (DZ)	2233	1537	24	35	18	47	-23	64	94	49	46	-24
Districts-WZ												
Colombo	586	403	17	24	21	45	30	13	19	18	45	36
Galle	3691	2541	1	2	2	206	187	0	1	1	223	209
Gampaha	1122	772	12	18	13	49	6	7	11	9	54	26
Kalutara	4569	3145	4	6	4	65	-1	2	4	2	77	15
Kandy	800	551	21	34	20	64	-3	10	19	13	89	27
Kegalle	5008	3446	3	5	3	73	9	1	2	2	91	31
Matara	2308	1589	16	24	13	52	-17	10	15	9	59	-8
Nuwara Eliya	2460	1693	11	17	10	53	-11	3	6	4	67	10
Ratnapura	6050	4164	5	8	5	54	-14	3	4	3	64	-2
Districts-DZ												
Ampara	3790	2608	28	41	21	44	-26	113	162	82	43	-27
Anuradhapura	1938	1334	55	80	41	46	-25	79	115	59	45	-26
Badulla	2697	1856	10	16	9	51	-18	22	34	19	53	-16
Batticaloa	2292	1577	11	17	9	49	-20	174	253	132	46	-24
Hambantota	2025	1394	57	83	43	45	-26	80	116	60	45	-26
Jaffna(1)	217	149	23	42	28	82	25	209	332	196	59	-6
Killinochchi	1031	710	102	146	75	44	-26	134	195	102	45	-24
Kurunegala	1041	717	46	68	36	49	-21	38	58	32	55	-14
Mannar	929	639	49	72	39	48	-21	22	34	20	58	-7
Matale	2770	1906	12	19	10	50	-19	18	27	15	54	-15
Monaragala	5562	3828	5	7	4	47	-20	14	21	12	50	-15
Mullaitivu	3144	2164	22	32	17	44	-26	76	110	58	46	-23
Polonnaruwa	9249	6366	19	27	14	44	-27	80	114	57	43	-28
Puttalam	538	370	71	107	58	49	-19	34	56	33	61	-3
Trincomalee	3080	2120	12	18	10	47	-22	94	135	69	44	-26
Vavuniya	2200	1514	53	76	39	44	-26	27	40	22	47	-21

TABLE 8.
Levels of scarcity of different units.

Unit	Scarcity level[1] according to the three indicators						
	Falkenmark		UN[2]			IWMI[3]	
	1991	2025	1991	2025		2025	
				Scenario 1	Scenario 2	Scenario 1	Scenario 2
Sri Lanka	N	M	MS-y	MS-b	M-b	M-b	N-b
Wet zone (WZ)	N	N	N-b	M-m	N-b	M-b	N-b
Dry zone (DZ)	N	M	S-y	S-y	S-y	S-y	N-b
Districts-WZ							
Colombo	MS	S	M-b	MS-m	MS-m	M-b	M-b
Galle	N	N	N-b	N-b	N-b	MS-b	MS-b
Gampaha	M	MS	M-m	M-b	M-m	M-b	M-y
Kalutara	N	N	N-b	N-b	N-b	M-b	N-b
Kandy	MS	MS	MS-m	MS-m	M-b	M-b	M-y
Kegalle	N	N	N-b	N-b	N-b	M-b	M-y
Matara	N	M	M-b	MS-m	M-m	M-b	N-b
Nuwara Eliya	N	M	M-m	M-m	N-b	M-b	N-b
Ratnapura	N	N	N-b	N-b	N-b	M-b	N-b
Districts-DZ							
Ampara	N	N	S-y	S-b	S-y	S-y	S-y
Anuradhapura	N	M	S-b	S-b	S-b	S-b	S-y
Badulla	N	N	MS-y	MS-y	M-y	M-b	N-b
Batticaloa	N	M	S-y	S-y	S-y	S-y	S-y
Hambantota	N	M	S-b	S-b	S-b	S-b	S-y
Jaffna(1)	S	S	S-y	S-b	S-y	S-y	S-y
Killinochchi	N	MS	S-b	S-b	S-b	S-b	S-b
Kurunegala	M	MS	S-m	S-b	MS-b	S-b	N-b
Mannar	MS	MS	S-m	S-m	SM-m	S-m	S-m
Matale	N	N	M-b	MS-y	M-y	M-b	N-b
Monaragala	N	N	M-y	M-y	M-y	M-b	N-b
Mullaitivu	N	N	S-y	S-y	S-y	S-y	S-y
Polonnaruwa	N	N	S-y	S-y	S-y	S-y	S-y
Puttalam	MS	S	S-m	S-b	S-m	S-b	S-m
Trincomalee	N	N	S-y	S-y	S-y	S-y	S-y
Vavuniya	N	M	S-m	S-m	SM-m	S-m	N-b

[1]N - Little or no water scarcity; M - Moderate water scarcity; MS - Medium to severe water scarcity; S - Severe water scarcity.

[2]b - Both seasons; m - maha season; y - yala season.

[3]MS, and M under IWMI criteria, respectively, indicate severe economic and moderate economic water scarcity.

Falkenmark Indicator

Per capita water supply is the basis for the Falkenmark criterion. Both current and future per capita water resources in Sri Lanka as a whole and also in the two climatic zones show no severe water scarcity (figure 4). However, five districts are already in the medium to severe water-scarce categories. Three more will enter into these categories by 2025. These 8 districts will have 46 percent of the total population, but contain only 25 percent of the land area and 22 percent of the irrigated area.

UN Indicator

The UN indicator addresses demand in terms of available water resources. This indicator also shows no severe water scarcity at national level at present or in the future. However, the dry zone in the yala season is already experiencing severe water scarcities.

At district level, seven districts in the maha season (21% of the population, 35% of the land area, and 44% of the irrigated area) are in the severe water-scarce category. Nine districts in the yala season (22% of the population, 43% of the land area, and 63% of the irrigated area) are in this category (figure 5).

The majority of the 1991 population (61%) lived in areas where water withdrawals were less than 20 percent of the water resources in each season. However, these areas contain only small percentages of the irrigated area (28% in maha and 19% in yala). The population in these areas depends on the food production from other districts that are relatively more water-scarce. This dependency is rather important because the irrigation sector has a substantial proportion of the present rice production. Therefore, any increase in the magnitude of water scarcities for the districts that are already water-scarce will have a substantial impact on the ability to meet the future food demand.

If the current rate of irrigation sector efficiency continues into the future the water-scarcity picture will become even worse. Under this scenario, the dry zone as a unit will have severe year-around water scarcities. Some districts in the dry zone will have major problems in meeting future demand under the existing level of irrigation efficiency. However, with the increased irrigation efficiency scenario most of these districts can meet their total 2025 demand by withdrawing water at or below the current level. Even under the increased irrigation efficiency scenario, four districts in the maha season and nine districts in the yala season are identified as severely water-scarce, as their withdrawals are still substantial percentages of the available water resources.

Under the UN indicator, the wet zone as a unit does not face serious water scarcity at present or in the future. However, some districts will have to increase their current withdrawals substantially to meet the 2025 demand.

IWMI Indicator

The future demands with respect to available water resources and also relative to the current demand are the basis for the IWMI water scarcity criteria (Seckler et al. 1998; Seckler, Barker and Amarasinghe 1999).

Under the first scenario, the 2025 water demand at national level is well below 50 percent of the available water resources, but will require an increase of about 49 percent over the 1991 withdrawal level. Thus at national level no severe (absolute or economic) water-scarce condition will exist by 2025. At the climatic zone level, the dry zone in the yala season will be in the absolute water-scarce condition. Some districts in the dry zone (7 in maha and 11 in yala) will face absolute water-scarce conditions in 2025 (figure 6). All districts in the wet zone, except Galle, will have no form of severe water scarcity. Galle district has ample water resources to develop its future demand. But this district will have year-around

FIGURE 4.
Falkenmark indicator of water scarcity.

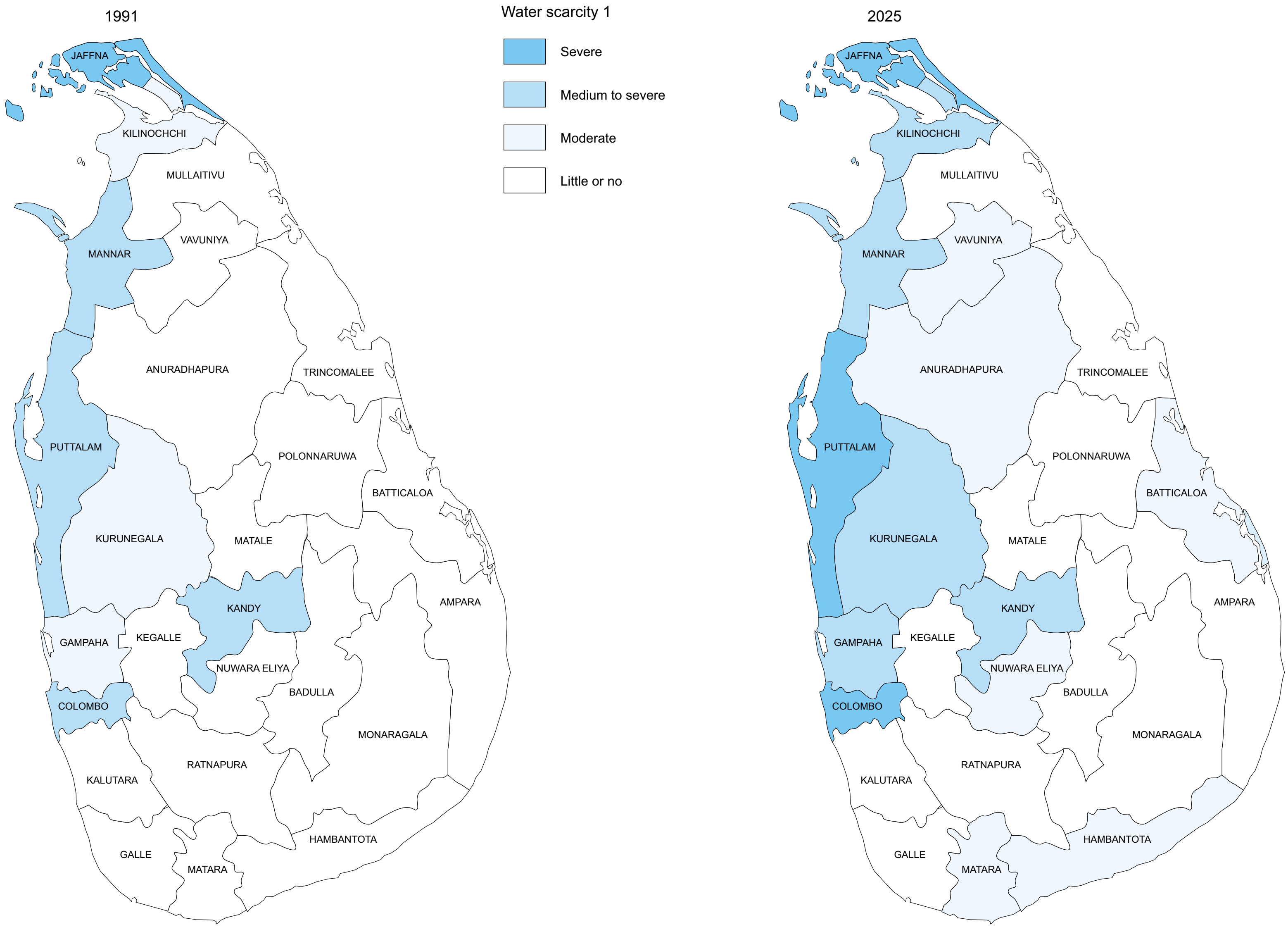


FIGURE 5.
UN indicator of water scarcity.

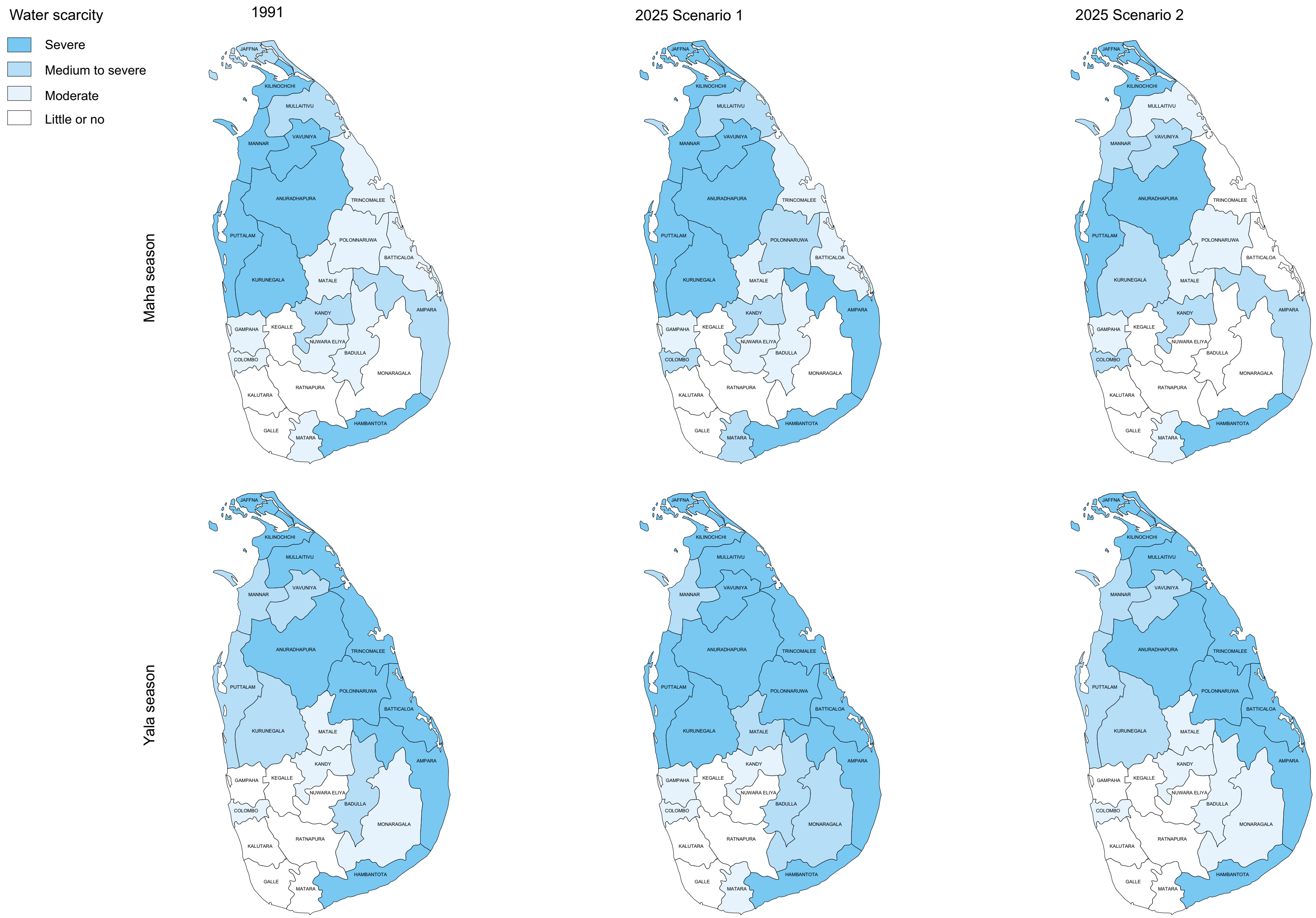
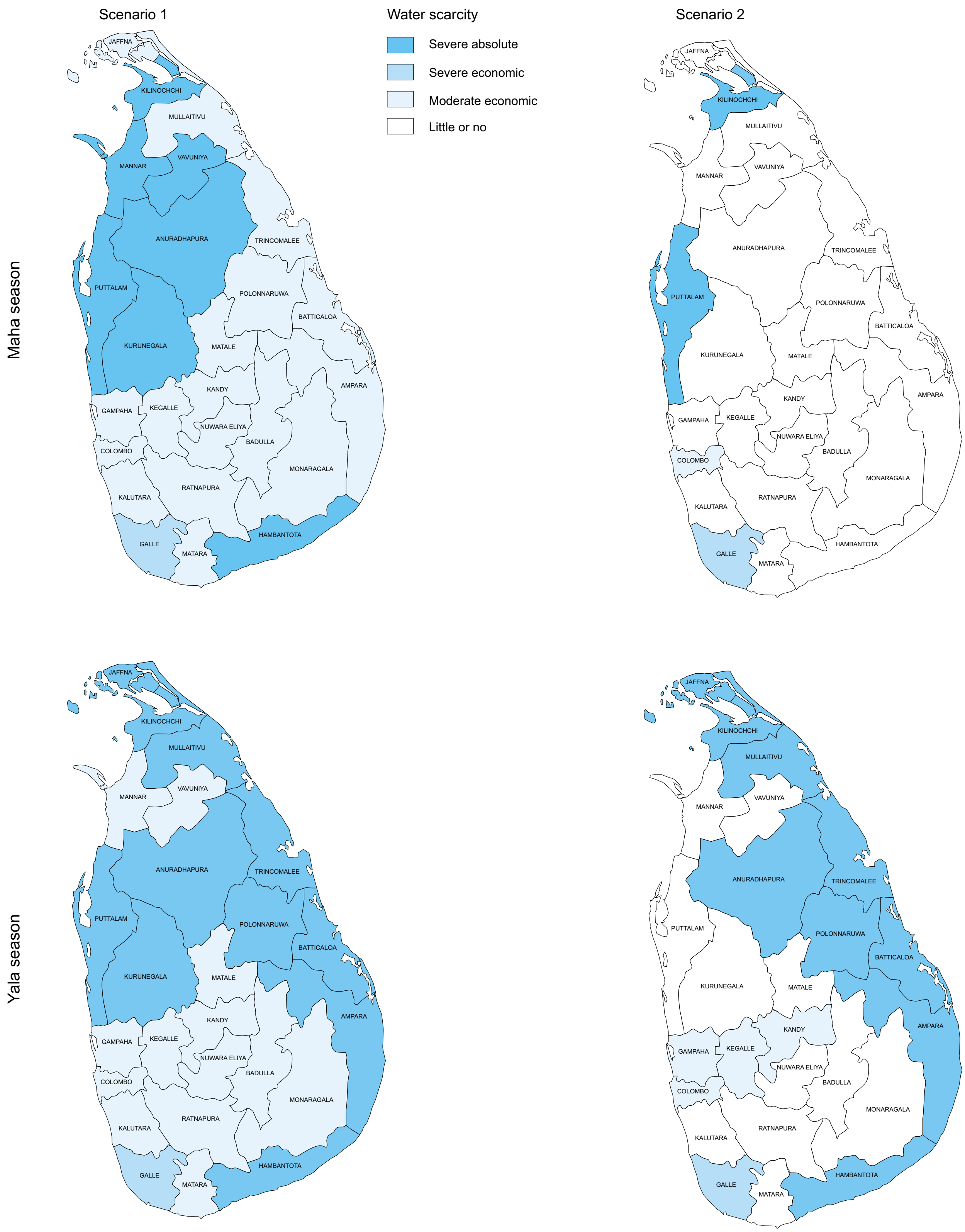


FIGURE 6.
IWMI indicator of water scarcity in 2025.



severe economic water scarcity as it will have to triple its 1991 withdrawal levels to meet the 2025 demand.

Under the increased efficiency scenario, only two districts (4% of the population) in the maha season, and nine districts (22% of the population) in the yala season are in the absolute water-scarce category. These districts are located in the dry zone. Under this scenario Galle district will still be in severe economic water-scarce conditions.

Comparisons of the Three Indicators

None of the water scarcity criteria indicate severe seasonal or year-round water scarcity at national level (table 8). However, there are several districts that are experiencing serious water scarcities at present or will enter into this category by the year 2025.

The Falkenmark indicator shows that almost half of the 2025 population will be in districts where per capita water availability is very low. This level of low water availability will be a severe constraint for further water resources development, especially for agriculture. Increases in food requirement in these areas will have to be met with imports either from the high per capita water availability areas within the country or from outside the country.

On the other hand, the high per capita water supply does not necessarily indicate the possibilities for further water resources developments. Both UN and IWMI indicators show that the demand with respect to water availability is high in some places where per capita water supply is very high.

For example, Ampara, Polonnaruwa, Trincomalee, and Mullaitive districts have very high annual per capita water resources. Under the same irrigation project efficiency scenario, these districts will face at least severe seasonal water scarcities according to UN and IWMI indicators. Therefore, for meeting future demand, they will have to increase their irrigation sector efficiencies or import water from other districts.

Some of the districts may have high per capita annual water resources and also low levels of current withdrawals compared to available water resources. These districts are not identified as water scarce by the Falkenmark and UN indicators. But the IWMI indicator identifies Galle district as severely water-scarce in the economic sense, which means that it will have to develop a substantial amount of withdrawals to meet agricultural, domestic, and industrial needs in 2025.

Conclusion

Results of the study show that aggregated national-level statistics on water scarcity are indeed misleading even for a small country like Sri Lanka in monsoonal Asia. National level statistics often ignore wide temporal and spatial variations of water availability and demand. Despite what national level statistics say, water availability in some districts will be a significant constraint for future social and economic development. Also, contrary to the common belief, some districts in the wet zone with ample per capita water supply will be severely water-scarce in the economic sense so that they will have to develop a substantial amount of withdrawals over the present level to meet their 2025 needs.

It should be noted here that all districts in the wet zone have a smaller share of the country’s irrigation withdrawal compared to the population. They will require more domestic and industrial withdrawals, and will depend heavily on the irrigated rice production from other districts. However, the major irrigated rice producing districts are already using a substantial amount of their available water resources.

If the current rate of irrigation efficiency continues in the future, several districts with major rice irrigated areas will have severe water scarcities according to UN and IWMI criteria. Some of these districts will be in serious water-scarce conditions so that the available water resources may not be adequate even to meet their projected demand. These districts will have to either reduce demand for irrigation by increasing irrigation efficiency or by importing food, or transport water from regions in the wet zone where water is abundant.

The increased irrigation sector efficiency scenario shows that, by doubling the irrigation efficiency, the total demand in 2025 of most water-scarce districts can be reduced by 50 percent. Under this scenario the savings of water in the agriculture sector are more than adequate to meet the future additional demands in the other two sectors.

Whether the country has the financial and institutional capacity to attain high irrigation efficiency in the second scenario is not clear. However, at the current irrigation efficiency level, the majority of dry zone districts will face either seasonal or year-round severe water scarcities.

Also the costs and benefits of increasing efficiency versus importing more food, or transporting water from water-abundant to water-scarce areas are not studied in this report. Because of current water scarcities in the major rice irrigating districts, these are important areas of research that are useful for future policy planning.

APPENDIX A.

Runoff Estimates of River Basins in Sri Lanka

For the current study, we estimate the primary discharges (runoff) to the sea from the river basins at 75 percent exceedence probability rainfall level. Long-Term Hydrometeorological Data in Sri Lanka (Nakagawa et al. 1995) is the data source for this analysis. There are 103 distinct natural river basins[6] in Sri Lanka covering 90 percent of the total land area. Of these, only a few river basins contain long-term monthly river discharge estimates. The period from 1945 to 1970 was considered for estimating the rainfall-runoff relationships. Here we assumed that no major development works were undertaken during this period. However, a few basins do contain some storage capacity constructed before 1945. In these basins, the estimated seasonal runoff was revised by adding the possible storage at the end of the season.

First, we estimate the seasonal (maha and yala) rainfall-runoff relationships for these basins. From the estimated relationship, we estimate the river discharge at 75 percent exceedence probability basin rainfall. For the basins where data are not available, we linearly interpolate the runoff estimates per unit area (mm) of the two adjoining basins. The average and the 75 percent runoff estimates for the maha and yala seasons, and the annual runoff at 75 percent and 50 percent exceedence probability level rainfall and also average rainfall are given in appendix table A. For the purpose of comparison, the annual average runoff in the National Atlas of Sri Lanka (Survey Department of Sri Lanka 1988) is given in the last column. The river basins are ordered anticlockwise starting from the Kelani basin, as indicated in the Sri Lankan Atlas.

Appendix table A shows that the average runoff values we estimated are almost equal to the average values given in the National Atlas of Sri Lanka (Survey Department of Sri Lanka 1988).

The average runoff estimate of most basins is more than the runoff estimated at 50 percent exceedence probability (median) rainfall level. This implies that in the long run the estimated average runoff cannot be expected even in 2 out of every 4 years. However, the runoff at 75 percent exceedence probability rainfall can be expected in at least 3 out of every 4 years in the long run. Therefore, the seasonal runoff at 75 percent exceedence probability rainfall is used in this report.

[6]In addition, there are 94 coastal basins with no significant contribution to freshwater resources (Arumugam 1969).

APPENDIX TABLE A.
Runoff estimates of river basins of Sri Lanka.

No.	Name of river basin	Drainage area	Seasonal runoff P75		Annual runoff			
					Estimate			Sri Lankan
			Maha	Yala	P75	P50	Average	Atlas average
		km^2	km^3	km^3	km^3	km^3	km^3	km^3
1	Kelani Ganga	2,278	2.33	2.97	5.30	5.63	5.75	5.47
2	Bolgoda Lake	374	0.41	0.50	0.92	0.99	1.02	0.75
3	Kaluganga	2,688	3.17	3.70	6.87	7.58	7.86	7.86
4	Bentota Ganga	760	0.73	0.85	1.58	1.75	1.81	1.54
5	Madu Ganga	59	0.07	0.08	0.15	0.17	0.17	0.15
6	Madampe Lake	90	0.10	0.12	0.23	0.25	0.26	0.17
7	Telwatte Ganga	51	0.06	0.07	0.13	0.14	0.15	0.10
8	Ratgama Lake	10	0.01	0.01	0.02	0.03	0.03	0.02
9	Gin Ganga	922	1.04	1.26	2.30	2.56	2.62	1.90
10	Koggala Lake	64	0.06	0.07	0.14	0.16	0.16	0.06
11	Polwatta Ganga	233	0.21	0.20	0.41	0.48	0.49	0.12
12	Nilwala Ganga	960	0.73	0.61	1.34	1.63	1.66	1.10
13	Sinimodara Oya	38	0.03	0.02	0.05	0.06	0.06	0.02
14	Kirama Oya	223	0.14	0.11	0.26	0.32	0.32	0.12
15	Rekawa Oya	92	0.04	0.03	0.08	0.10	0.10	0.04
16	Urubokke Oya	348	0.18	0.14	0.32	0.39	0.40	0.20
17	Kachigala Ara	220	0.10	0.07	0.18	0.22	0.22	0.06
18	Walawe Ganga	2,442	0.98	0.66	1.65	2.06	2.14	2.17
19	Karagan Oya	58	0.02	0.01	0.03	0.04	0.04	0.02
20	Malala Oya	399	0.11	0.08	0.19	0.24	0.25	0.07
21	Embilikala Oya	59	0.01	0.01	0.02	0.03	0.03	0.02
22	Kirindi Oya	1,165	0.20	0.15	0.35	0.43	0.46	0.48
23	Bambawe Ara	79	0.01	0.01	0.02	0.03	0.03	0.03
24	Mahasilawa Oya	13	0.00	0.00	0.00	0.00	0.00	0.01
25	Butawa Oya	38	0.01	0.00	0.01	0.01	0.01	0.02
26	Menik Ganga	1,272	0.17	0.08	0.25	0.32	0.30	0.49
27	Katupila Aru	86	0.01	0.00	0.02	0.02	0.02	0.03
28	Kuranda Ara	131	0.02	0.01	0.03	0.04	0.04	0.05
29	Namadagas Ara	46	0.02	0.01	0.03	0.04	0.04	0.04
30	Kambe Ara	46	0.01	0.00	0.01	0.02	0.02	0.02
31	Kumbukkan Oya	1,218	0.30	0.05	0.36	0.47	0.48	0.77
32	Bangura Oya	92	0.02	0.00	0.03	0.04	0.04	0.04
33	Girikula Oya	15	0.00	0.00	0.01	0.01	0.01	0.01
34	Heawa Ara	51	0.02	0.00	0.02	0.02	0.02	0.03
35	Wila Ara	484	0.15	0.02	0.17	0.22	0.24	0.22
36	Heda Oya	604	0.23	0.02	0.25	0.34	0.36	0.39
37	Karanda Oya	422	0.17	0.01	0.18	0.24	0.26	0.20
38	Simena Ara	51	0.02	0.00	0.02	0.03	0.03	0.03
39	Tandiadi Aru	22	0.01	0.00	0.01	0.01	0.01	0.02
40	Kangikadichi Ara	56	0.02	0.00	0.03	0.03	0.04	0.04
41	Rufus Kulam	35	0.01	0.00	0.02	0.02	0.02	0.02
42	Pannel Oya	184	0.08	0.00	0.09	0.11	0.12	0.13
43	Ambalama Oya	115	0.05	0.00	0.05	0.07	0.08	0.08
44	Gal Oya	1,792	0.82	0.03	0.86	1.11	1.26	1.25
45	Andella Oya	522	0.24	0.01	0.25	0.33	0.37	0.29
46	Thumpankeni Tank	9	0.00	0.00	0.00	0.01	0.01	0.01
47	Namakada Aru	12	0.01	0.00	0.01	0.01	0.01	0.01
48	Mandipattu Aru	100	0.05	0.00	0.05	0.07	0.08	0.09
49	Pattanthe Dephue Aru	100	0.01	0.00	0.01	0.02	0.02	0.09
50	Magalatavan Aru	346	0.18	0.00	0.18	0.23	0.27	0.29

(Continued)

No.	Name of river basin	Drainage area	Seasonal runoff P75		Annual runoff			
					Estimate			Sri Lankan
			Maha	Yala	P75	P50	Average	Atlas average
		km²	km³	km³	km³	km³	km³	km³
51	Vett Aru	26	0.01	0.00	0.01	0.02	0.02	0.02
52	Mundeni Aru	1,280	0.58	0.02	0.60	0.77	0.88	0.86
53	Miyangollal Ela	225	0.09	0.00	0.09	0.12	0.13	0.12
54	Maduru Oya	1,541	0.50	0.04	0.54	0.75	0.75	0.81
55	Pulliyanpotha Aru	52	0.02	0.00	0.02	0.03	0.03	0.03
56	Kirimechi Odai	77	0.03	0.01	0.04	0.05	0.05	0.04
57	Bodigoda Aru	164	0.07	0.02	0.09	0.11	0.12	0.08
58	Mandan Aru	13	0.01	0.00	0.01	0.01	0.01	0.01
59	Makarachchi Aru	37	0.02	0.01	0.03	0.03	0.03	0.02
60	Mahaweli Ganga	10,327	5.37	2.71	8.08	9.09	9.72	11.02
61	Kantalai Basin Per Ara	445	0.13	0.01	0.14	0.20	0.20	0.15
62	Panna Oya	69	0.02	0.00	0.02	0.03	0.03	0.03
63	Palampotta Aru	143	0.03	0.00	0.04	0.05	0.06	0.06
64	Pankulam Ara	382	0.08	0.01	0.09	0.13	0.14	0.17
65	Kanchikamban Aru	205	0.04	0.00	0.04	0.06	0.07	0.08
66	Palakutti Aru	20	0.00	0.00	0.00	0.01	0.01	0.01
67	Yan Oya	1,520	0.20	0.02	0.22	0.36	0.38	0.30
68	Mee Oya	90	0.01	0.00	0.01	0.02	0.02	0.03
69	Ma Oya	1,024	0.13	0.01	0.15	0.24	0.26	0.31
70	Churian Aru	74	0.01	0.00	0.01	0.02	0.02	0.03
71	Chavar Aru	31	0.00	0.00	0.00	0.01	0.01	0.01
72	Palladi Aru	61	0.01	0.00	0.01	0.01	0.02	0.02
73	Nay ARa	187	0.02	0.00	0.03	0.04	0.05	0.07
74	Kodalikallu Aru	74	0.01	0.00	0.01	0.02	0.02	0.03
75	Per Ara	374	0.05	0.01	0.05	0.08	0.09	0.12
76	Pali Aru	84	0.01	0.00	0.01	0.02	0.02	0.03
77	Muruthapilly Aru	41	0.00	0.00	0.01	0.01	0.01	0.02
78	Thoravil Aru	90	0.01	0.00	0.01	0.02	0.02	0.03
79	Piramenthal Aru	82	0.01	0.00	0.01	0.02	0.02	0.03
80	Nethali Aru	120	0.01	0.00	0.02	0.02	0.03	0.03
81	Kanakarayan Aru	896	0.10	0.02	0.12	0.18	0.22	0.02
82	Kalawalappu Aru	56	0.01	0.00	0.01	0.01	0.01	0.01
83	Akkarayan Aru	192	0.02	0.00	0.02	0.04	0.05	0.04
84	Mendekal Aru	297	0.03	0.01	0.04	0.06	0.07	0.08
85	Pallarayan Kadu	159	0.02	0.00	0.02	0.03	0.04	0.05
86	Pali Aru	451	0.05	0.01	0.06	0.08	0.11	0.11
87	Chappi Aru	66	0.01	0.00	0.01	0.01	0.02	0.02
88	Parangi Aru	832	0.08	0.02	0.10	0.15	0.20	0.27
89	Nay Aru	560	0.06	0.01	0.07	0.10	0.13	0.12
90	Malvatu Oya	3,246	0.32	0.08	0.40	0.58	0.77	0.57
91	Kal Ara	210	0.02	0.01	0.02	0.04	0.05	0.04
92	Moderagam Ara	932	0.08	0.03	0.11	0.17	0.23	0.16
93	Kala Oya	2,772	0.23	0.08	0.31	0.50	0.68	0.59
94	Moongil Aru	44	0.00	0.00	0.00	0.01	0.01	0.01
95	Mi Oya	1,516	0.12	0.01	0.13	0.21	0.26	0.34
96	Madurankuli Aru	62	0.01	0.00	0.01	0.01	0.01	0.03
97	Kalagamuwa Oya	151	0.02	0.01	0.03	0.04	0.05	0.05
98	Pantampola Oya	215	0.04	0.02	0.05	0.07	0.08	0.07
99	Deduru Oya	2,616	0.52	0.26	0.78	0.98	1.13	1.61
100	Karambala Oya	589	0.17	0.12	0.29	0.35	0.37	0.25
101	Ratmal Oya	215	0.08	0.07	0.15	0.17	0.18	0.09
102	Maha Oya	1,510	0.69	0.61	1.31	1.53	1.54	1.61
103	Attanagalu Oya	727	0.54	0.62	1.16	1.27	1.29	1.57
	Total	59,671	24.14	16.91	41.05	48.04	50.89	50.59

APPENDIX B.

Irrigation Requirement

The irrigation requirement for each district is given in appendix table B. The net evapotranspiration (NET), for a period of 1 month is defined as the evapotranspiration for the reference crop (ETo) minus the effective rainfall. The effective rainfall is a fraction of the average rainfall. To calculate this fraction, first the total average rainfall volume and the runoff volume generated from this rainfall on a unit are calculated. The difference between the rainfall and runoff volumes is the fraction of rainfall that is available at the place of rainfall occurrence. We further assume that 10 percent of this difference is lost as deep percolation, and the remaining 90 percent as the effective rainfall is available for crop use. As mentioned by Seckler et al. (1998), in the case of rice we multiply the ETo by 110 percent to obtain NET for rice. This is because most rice fields are flooded during land preparation and the flooded water surface is prone to higher evaporation. If the difference between ETo and effective rainfall is negative, NET for the month is taken to be zero, i.e., there is no irrigation requirement for that month.

The NET for the maha season is the sum of the NETs for the five months from October to February. The NET for the yala season is the sum of the NETs for the four months from April to July. The monthly ETo and average rainfall data for each district were obtained from the Climate and Water Atlas (IIMI and Utah State University 1997).

The computation of NET on irrigated area is shown in appendix table B. The rice and OFC-irrigated areas in the 1991 maha season are in C1 and C2, respectively. The 1991 yala season data are in columns C7 and C8. The irrigated rice area data were obtained from the Department of Census and Statistics 1995, and the irrigated OFC area data were obtained from Jayawardana, Jayasinghe, and Dayarathne 1993. The NETs for the maha season rice and OFC are given in C3 and C4, and the NETs for the yala season irrigated rice and OFC are in C8 and C9.

The total NETs (C6, C12) on the irrigated area for maha and yala seasons as depths are given in C5 and C11.

APPENDIX TABLE B.

Unit	Maha season, 1991						Yala season, 1991					
	Irrigated area		NET				Irrigated area		NET			
	Paddy	OFC	Paddy	OFC	on irr. area		Paddy	OFC	Paddy	OFC	on irr. area	
					Depth	Total					depth	total
	1,000ha	1,000ha	m	m	m	km^3	1,000ha	1,000ha	m	m	m	km^3
	C1[1]	C2[1]	C3	C4	C5	C6[1]	C7[1]	C8[1]	C9	C10	C11	C12[1]
Sri Lanka	347.8	28.3	0.23	0.19	0.19	0.70	227.29	38.87	0.30	0.25	0.28	0.76
Wet Zone (WZ)	13.5%	0.3%	0.33	0.28	0.27	18.4%	16.4%	3.2%	0.22	0.17	0.17	8.8%
Dry Zone (DZ)	86.5%	99.7%	0.17	0.14	0.17	81.6%	83.6%	96.8%	0.35	0.30	0.30	91.2%
Districts-WZ												
Colombo	0.2%		0.45	0.39	0.45	0.5%	0.3%		0.31	0.27	0.31	0.3%
Galle	0.0%		0.46	0.40	0.46	0.1%	0.1%		0.30	0.25	0.30	0.0%
Gampaha	1.1%		0.34	0.28	0.34	1.8%	1.1%		0.20	0.15	0.20	0.7%
Kalutara	0.9%		0.43	0.38	0.43	2.0%	1.3%		0.29	0.25	0.29	1.2%
Kandy	3.5%		0.17	0.14	0.17	3.0%	4.3%	2.4%	0.09	0.04	0.08	1.2%
Kegalle	0.7%		0.32	0.26	0.32	1.2%	1.1%		0.19	0.15	0.19	0.6%
Matara	2.3%		0.37	0.32	0.37	4.2%	2.8%		0.26	0.21	0.26	2.2%
Nuwara Eliya	1.7%		0.18	0.15	0.18	1.5%	1.4%		0.14	0.10	0.14	0.6%
Ratnapura	2.9%	0.3%	0.28	0.23	0.28	4.0%	4.0%	0.8%	0.17	0.12	0.16	2.0%
Districts-DZ												
Ampara	11.1%	0.1%	0.19	0.15	0.19	10.4%	19.8%	2.9%	0.29	0.24	0.29	17.8%
Anuradhapura	15.5%	1.8%	0.16	0.14	0.16	12.3%	6.8%	39.6%	0.35	0.30	0.33	13.4%
Badulla	5.3%	0.5%	0.15	0.13	0.15	4.1%	4.5%	4.4%	0.22	0.17	0.21	3.4%
Batticaloa	3.5%	8.0%	0.14	0.10	0.13	2.7%	4.6%		0.37	0.32	0.37	5.2%
Hambantota	7.8%	16.9%	0.23	0.19	0.22	10.2%	10.3%	3.9%	0.30	0.25	0.29	9.6%
Jaffna(1)	0.0%	15.3%	0.15	0.13	0.13	0.8%	0.0%	8.7%	0.51	0.46	0.46	2.0%
Killinochchi	2.6%	4.2%	0.15	0.13	0.15	2.1%	0.4%	2.5%	0.50	0.44	0.47	1.2%
Kurunegala	11.5%	0.6%	0.21	0.17	0.21	11.9%	9.8%	23.8%	0.16	0.11	0.14	6.0%
Mannar	0.7%	5.6%	0.17	0.15	0.16	0.9%	0.2%		0.42	0.36	0.42	0.3%
Matale	3.2%	0.4%	0.17	0.15	0.17	2.8%	1.7%	3.4%	0.28	0.23	0.27	1.8%
Monaragala	2.9%	0.1%	0.14	0.12	0.14	2.0%	1.8%	0.6%	0.22	0.17	0.22	1.2%
Mullaitivu	1.5%	13.4%	0.14	0.12	0.13	1.6%	0.6%		0.48	0.43	0.48	0.8%
Polonnaruwa	12.1%	2.7%	0.18	0.15	0.18	11.1%	16.8%		0.41	0.36	0.41	20.8%
Puttalam	2.8%	8.1%	0.22	0.18	0.21	3.7%	2.0%	4.2%	0.16	0.12	0.15	1.2%
Trincomalee	4.4%	0.0%	0.12	0.10	0.12	2.7%	4.2%		0.45	0.40	0.45	5.8%
Vavuniya	1.6%	22.0%	0.15	0.13	0.14	2.3%	0.1%	2.9%	0.44	0.38	0.39	0.7%

[1]Wet-zone, dry-zone, and district values are given as a percent of the Sri Lankan total.

Literature Cited

Aluwihare, P. B.; and M. Kikuchi. 1991. *Irrigation investment trends in Sri Lanka: New construction and beyond.* Colombo, Sri Lanka: International Irrigation Management Institute.

Arumugam, S. 1969. *Water resources of Ceylon: Its utilization and development.* Colombo, Sri Lanka: Water Resources Board.

Department of Census and Statistics. 1995. *Statistical abstract of the Democratic Socialist Republic of Sri Lanka 1994.* Colombo, Sri Lanka: Department of Census and Statistics.

Engelman, R.; and P. Leroy. 1993. *Sustaining water: Population and the future of renewable water supplies.* Population and Environment Program. Washington, D.C.: Population Action International.

Economic and Social Commission for Asia and the Pacific (United Nations). 1995. *Guidebook to water resources, use and management in Asia and the Pacific. Volume one: Water resources and water use.* Water resources series no.74. New York, NY, USA: United Nations.

Falkenmark, Malin; Jan Lundqvist; and Carl Widstrand. 1989. Macro-scale water scarcity requires micro-scale approaches: Aspects of vulnerability in semi-arid development. *Natural Resources Forum* 13 (4): 258-267.

Gleick, Peter H., ed. 1996. Basic water requirements for human activities: Meeting basic needs. *Water International* 21(2): 83-92.

International Irrigation Management Institute (IIMI) and Utah State University. 1997. *World water and climate atlas.* Colombo, Sri Lanka: International Irrigation Management Institute.

Irrigation Department. 1975. *Register of irrigation projects in Sri Lanka.* Colombo, Sri Lanka: Irrigation Department.

Jayawardana, J.; Ananda Jayasinghe; and P.W.C. Dayarathne. 1993. Promoting implementation of crop diversification in rice-based irrigation systems in Sri Lanka. In *Promoting crop diversification in rice-based irrigation systems,* ed. Senen M. Miranda and R. Maglinao. Colombo, Sri Lanka: International Irrigation Management Institute.

Mahaweli Authority of Sri Lanka. 1995. *Mahaweli statistical handbook 1994.* Colombo, Sri Lanka: Mahaweli Authority of Sri Lanka.

Nakagawa, K.; H. Edagawa; V. Nandakumar; and M. Aoki. 1995. *Long-term hydrometeorological data in Sri Lanka: Data book of hydrological cycles in humid tropical ecosystems, Part I.* Japan: University of Tsukuba.

Raskin, P.; P. Gleick; P. Kirshen; G. Pontius; and K. Strzepek. 1997. *Water futures: Assessment of long-range patterns and problems.* Stockholm, Sweden: Stockholm Environment Institute.

Sakthivadivel, R.; C. R. Panabokke; C. M. Wijayaratna; N. Fernando; K. Jinapala; and R. B. Bandula Sirimal. 1995. *Natural resources management study of North Central Province Sri Lanka. Annexures - Volume II: Pre-project technical assistance study for proposed Area Development Project of North Central Province.* Colombo: International Irrigation Management Institute.

Samad, M. 1997. Personal communication.

Seckler, D.; Upali. A. Amarasinghe; David Molden; Radhika de Silva; and Randy Baker. 1998. *World water demand and supply 1990 to 2025: Scenarios and issues.* Research Report 19. Colombo: International Irrigation Management Institute.

Seckler, D.; Randy Barker; and Upali A. Amarasinghe. 1999. Water scarcity in the twenty-first century. *International Journal of Water Resources Development* 15(1/2):29-42.

Survey Department of Sri Lanka. 1988. *The national atlas of Sri Lanka.* Sri Lanka: Survey Department of Sri Lanka.

United Nations. 1995. *World population prospects: The 1994 revision.* New York, NY, USA: United Nations.

Wijayaratna, C. M.; and K. Hemakeerthi. 1992. Production and profitability of rice cultivation in Sri Lanka under different water regimes: A trend analysis. In *Advancements in IIMI's research 1992: A selection of papers presented at the Internal Program Review,* ed. International Irrigation Management Institute, 277-308. Colombo, Sri Lanka: International Irrigation Management Institute.

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